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THE SEQUENCE OF EVENTS GENERATOR A POWERFUL TOOL FOR MISSION OPERATIONS

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Abstract - *The functions and features of the Sequence of Events (SOE) and Flight Operations Procedures (FOP) generator developed and used at DLR/GSOC for the positioning of EUTELSAT II satellites are presented. The SOE and FOP are the main operational documents that are prepared for nominal as well as for non-nominal mission execution. Their structure and application is described. Both of these documents are generated, validated and maintained by a common software tool. Its main features and advantages are demonstrated. The tool has been improved continuously over the last 5 years. Due to its flexibility it can easily be applied to other projects, new features may be added.*

1 INTRODUCTION

The German Space Operations Center (GSOC) has been in charge for the positioning of various geostationary spacecraft during the last twenty years. The main operational documents for mission planning and execution of the Launch and Early Orbit Phase (LEOP) are compiled in the Operations Plan. It consists of TM/TC dictionaries, procedures for satellite, ground and flight dynamic operations as well as the Sequence of Events (SOE).

For the EUTELSAT II project a special software tool is used which allows for an easy and flexible generation of such a consistent SOE. The experience gained by the application of this tool during several missions led to the implementation of many additional features for ease of mission preparation and execution.

2 HISTORY

All the above mentioned elements of the Operations Plan were already applied for the SYMPHONIE

satellites, the first geostationary spacecraft positioned by GSOC in the mid seventies. These documents were typewritten without exception whereas last minute changes and updates appeared just as handwritten redline copies. All the timing functions as well as consistency checks in the preparation phase had to be done manually.

The TV-SAT direct broadcasting satellites were launched and positioned in the mid to the late eighties. For these spacecraft the Operations Plan documentation was produced by an electronic writing system using extracts of the original manufacturers operations handbook as prime input. TM/TC dictionaries were partially generated from the operational databases. A simple SOE generator was installed on a large scale computer, providing some limited features for mission timeline generation, mainly in the field of timing:

- time conversion from reference times into UTC
- time calculations
- consistency checks w.r.t. timing constraints
- automatic step (re-)arranging (e.g. in case of adding new steps)

The Sequence of Events was printed out in a fixed predefined format on a lineprinter.

For the DFS communication satellites, positioned during the late eighties and the early nineties, all information required for mission operations execution was incorporated in the SOE as one single applicable document including all operations procedures. This SOE was produced, printed and distributed for each mission event. Due to the complexity of this document most of the mission operations staff was supplied with special tailored extracts (e.g. subsystem, flight dynamic, ground data system extracts etc.). In order to handle such a comprehensive document a special Sequence of Events generator was developed on a mainframe computer. Main task of this software was to provide

a tool for easy and safe generation of a consistent mission sequence and the respective extracts. Since the early nineties GSOC is positioning the satellites of the EUTELSAT II series. For this project the initial philosophy was used, having the operations procedures as separate documents with the SOE as the guiding document.

The SOE generator developed for the DFS-project was found to be a very useful tool for the handling of the flight operations documentation. It was transferred to PCs and adapted to the project needs; its features and functions are pointed out in the following paragraphs. A simplified survey of the SOE generation process is depicted in Figure 1.

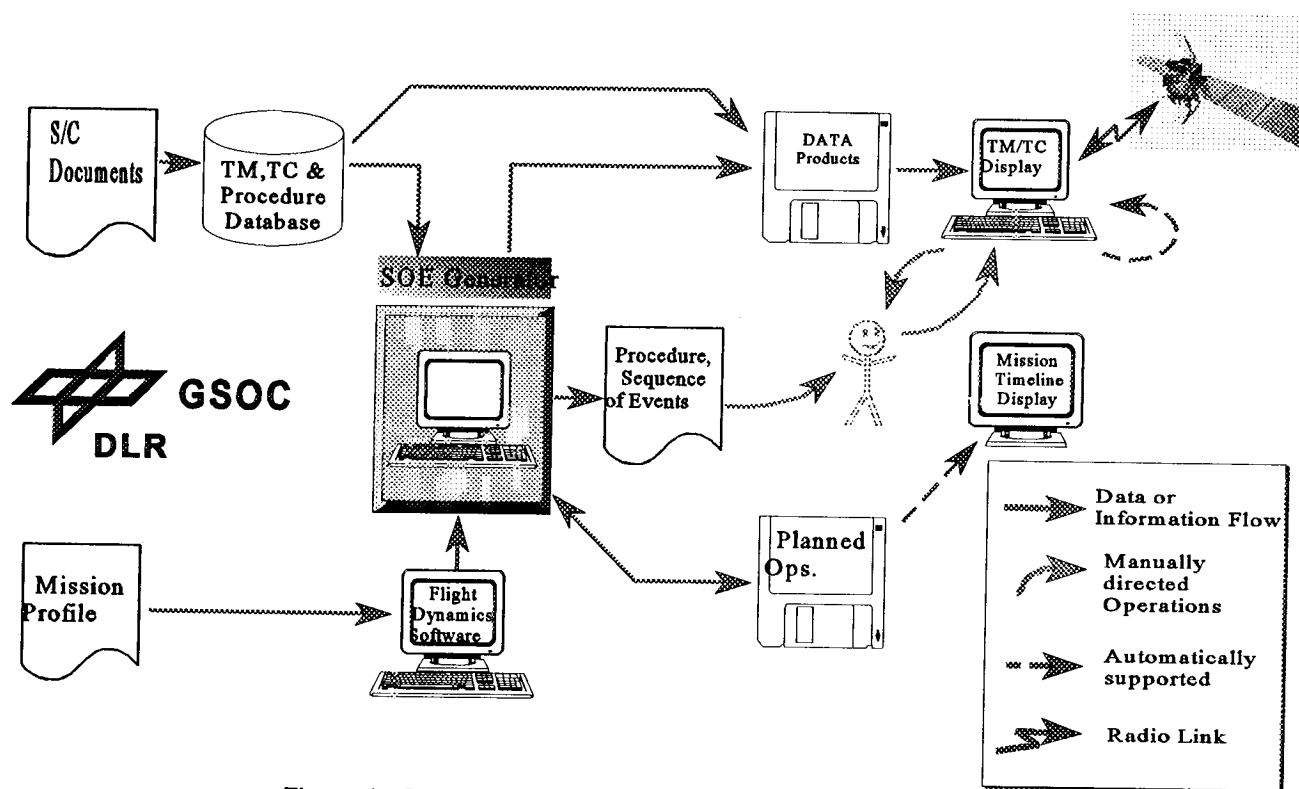


Figure 1: Sequence of Events Generation for EUTELSAT II LEOP

3 OPERATIONAL DOCUMENTATION

3.1 PROCEDURES

The satellite procedures provide detailed description of all nominal and contingency operations. They

define step by step all relevant activities including S/C surveillance, commanding and command verification to change the S/C from one stable and well defined configuration into a new one. The S/C manufacturer operations descriptions are complemented by indication of applicable reference

times, operational TM/TC mnemonics and references to the appropriate display masks as well as to the use of online supporting tools. The procedures are organized in substeps which contain only one single telecommand, telemetry verification or directives to the ground staff. Each substep can be flagged for which subsystem it is relevant or what constraints must be met. This allows to produce extracts for different user groups and to check the feasibility of the planned operation. Reference times which are assigned to all substeps allow to create a consistent operations timeline.

3.2 THE SEQUENCE OF EVENTS

The Sequence of Events is the controlling document for the execution of the mission. It coordinates all requirements and constraints arising from mission profile, S/C technology and ground network availability. The SOE provides the mission operations plan and specifies step by step all mission events and activities from launch through injection into the geosynchronous position. Activities are satellite operations, ground operations or flight dynamic operations.

As a mission timeline the SOE specifies item by item the relevant step to be performed in the mission, it indicates go/no-go decision points and orbit related information as:

- apogees, perigees, eclipses
- sensor visibilities, sun/moon interferences
- RF contact conditions
- maneuver start / stop times
- ground station visibilities
- ranging schedule

Reference is made to the respective procedures, only selected substeps of these procedures which are of general interest are reproduced in the SOE.

3.3 APPLICATION

During the whole LEOP each party of the mission operations team gets its directives from the SOE as the common guiding operational document. It is

valid for all nominal and contingency operations and is used in combination with the respective operations procedures :

- Satellite procedures for Flight Operations team
- Ground procedures for Ground Data System team
- Flight Dynamic procedures for Flight Dynamics team

According to the mission analysis the SOE is prepared before launch for the nominal positioning sequence which is for EUTELSAT II a 3-impulse strategy. Backup strategies in case of maneuver postponements are also considered in the SOE in advance in order to guarantee a save continuation of all operations in such a case. Figure 2 shows a typical maneuver tree of a 3-impulse LEOP strategy including all prepared backup cases.

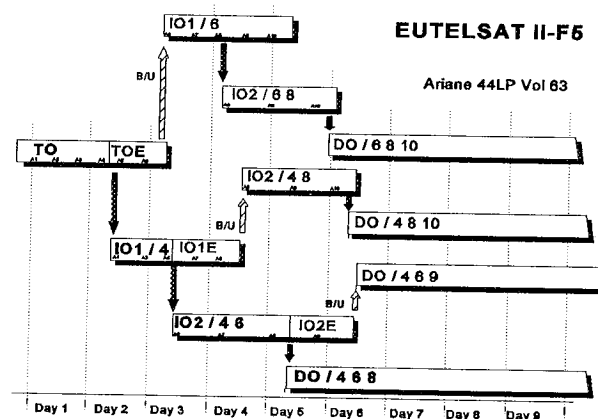


Figure 2: Typical maneuver tree for a 3-impulse LEOP strategy

Due to the fact that all online changes of the mission profile in case of launch delays, severe injection errors and ground or satellite contingencies only affect the SOE, all procedures remain valid and unchanged. The updates of mission operations documentation are minimized and can be introduced in a flexible, quick and safe way by means of the SOE generator.

4 THE SOE GENERATOR

The SOE generator software is written in high level programming languages linked to an application of a standard database software.

4.1 DATABASES

All information for flight procedures is stored in a relational database - the procedure database - containing several tables. The most important and comprehensive table contains the procedure steps. They are generated and validated with the Editor of the SOE generator. Inputs are provided by the satellite operations manual and design summary. Other tables are extracts of TM and TC databases, tables of the spacecraft attitude control modes, assignments of actions, available resources, constraints and affected subsystems.

The link from the original TM/TC databases to the procedure database ensures consistency of all these critical data. Throughout software development, mission plan preparation and mission execution the same databases are used by all parties thus minimizing effort and risks. There are no changes in this field without being driven and/or being documented by these databases.

The TM/TC databases are derived either from manufacturer delivered tables or files, complemented by information of S/C design summary and user defined information (e.g. TM/TC mnemonics). Operational products extracted from these databases are:

- TM/TC dictionaries
- all processing information for command system and TM-processor including alarm limits
- automatic TC execution verification database

4.2 PLANNING SOFTWARE

EDITOR AND VALIDATION

A comfortable menu system gives access to the various tools for handling of the procedure database.

A special editor allows to generate the procedures in a simple and safe way. Many automatic functions are triggered by single entries using information stored in the database:

- conversion of TM parameters into acronyms
- translation of TC codes into mnemonics
- functional description of TM/TC
- indication of display mask reference numbers
- generation of correct TC-datawords
- push-button queries for TM/TC codes
- suggestion of TM status parameter outputs

In addition the editor allows beside all standard functions to calculate and shift time labels and to branch into subprocedures. Each substep is automatically labelled with the date of its latest update for control purposes and automatic generation of change bars in the documentation.

Various validate functions allow to check the integrity of the database. In particular the following checks are supported:

- step records exist for all procedures
- no unnecessary step records exist for a procedure
- no step records exist without procedure header
- all codes have entries in the acronym tables
- all referenced subprocedures exist
- procedure duration matches the end time of last step
- TM/TC fields in procedures match with contents of TM/TC lookup tables

Inconsistencies found at validation may be corrected automatically in the database. Steps that require updates in the document printouts due to changes in the database are indicated by the validate utility.

The printout of procedures as a predefined database report is initialized by the editor tool. Layout changes of the output format for special extracts, testing purpose and for adaption to new missions can be freely chosen.

CHECKER AND FORMATTER

Task of the Checker and Formatter is the generation and validation of a consistent mission timeline. It directly accesses the procedure database.

Any field of the database can be selected by the user

to be implemented in the timeline. In addition the checker provides some further fields, such as absolute times and overall step number. The checker calculates absolute times for every single substep using freely definable time labels or absolute UTC time, whereas the procedures contain an internal chronology.

Orbital events which are the filtered output of the flight dynamics software are interleaved with the scheduled procedures (e.g. eclipses, acquisition of signal by ground stations, S/C geometry dependent constraints). By including all these data the SOE provides also information about margins and constraints to be considered in case of contingencies.

Various checks can be enabled in the checker's menu to confirm consistency of the generated mission sequence. These checks can be performed at procedure level, record level or for the timeline files and validate mainly following criteria:

- Chronological: making sure that start times are in chronological order
- Sequential: making sure that all elements are strictly sequential without overlapping
- Duration : checking for finite duration of records
- Constraints: checking for violation of constraints

A typical LEOP sequence consists of about 2500 steps each containing several substeps. Every single substep is verified by a number of checks like the above mentioned. To give an example: For each command activity in the mission timeline it is checked that a ground station is scheduled for uplink and no ranging is in progress. A number of checks like these are performed for every single substep counting a multiple of the 2500 main steps of a typical LEOP.

For the mission sequence printout the formatter module allows to specify output filters and sort orders to produce extracts for different parties. As for the procedures the print-layout of the SOE may be freely defined if required.

GRAPHICAL SEQUENCE EDITOR

The scheduling tasks necessary for a LEOP are relatively trivial compared to scientific missions. On the other hand some of the requirements and constraints are not absolutely fixed and may be negotiated between affected parties. In order not to overpower the SOE generator an automatic scheduler was not implemented. As a practicable approach an interactive graphical tool was introduced to manipulate the input files for the checker and formatter. All necessary information is provided in a graphical display as plot versus time. Different coloured boxes indicate start and stop times of

- station visibilities
- station schedule (prime / backup)
- satellite flight procedures
- rangings
- eclipses

In addition orbital information directly retrieved from flight dynamics software is plotted:

- apogees / perigees
- eclipses
- collinearity regions
- min/max altitude constraints
- sun/moon interferences

A supplementary window can be selected which shows schematically the S/C position and orbit geometry as well as the above mentioned orbital information. It allows to verify the regular distribution of rangings which is a non-linear function of the time. The sequence is edited and modified in an alphanumeric window at the lower part of the display. Editing uses automatic functions to a maximum extent thus minimizing the manual inputs. Entries are mainly keywords that can be converted into plane text by function key. All changes in the alphanumeric parts lead online to respective changes in the graphical presentation. By having this prompt graphical response to manual inputs eventual discrepancies can be detected and corrected immediately. Time consuming checker runs have to be performed less frequently.

The timescale of the displayed timeline can be selected in the range of 30 minutes for detailed analysis to the whole mission duration (about 2 weeks) for general overview.

Jumping to selected parts of the sequence may be done either by scrolling with cursor keys or by selecting the respective branch of the maneuver tree which is provided on a special display page.

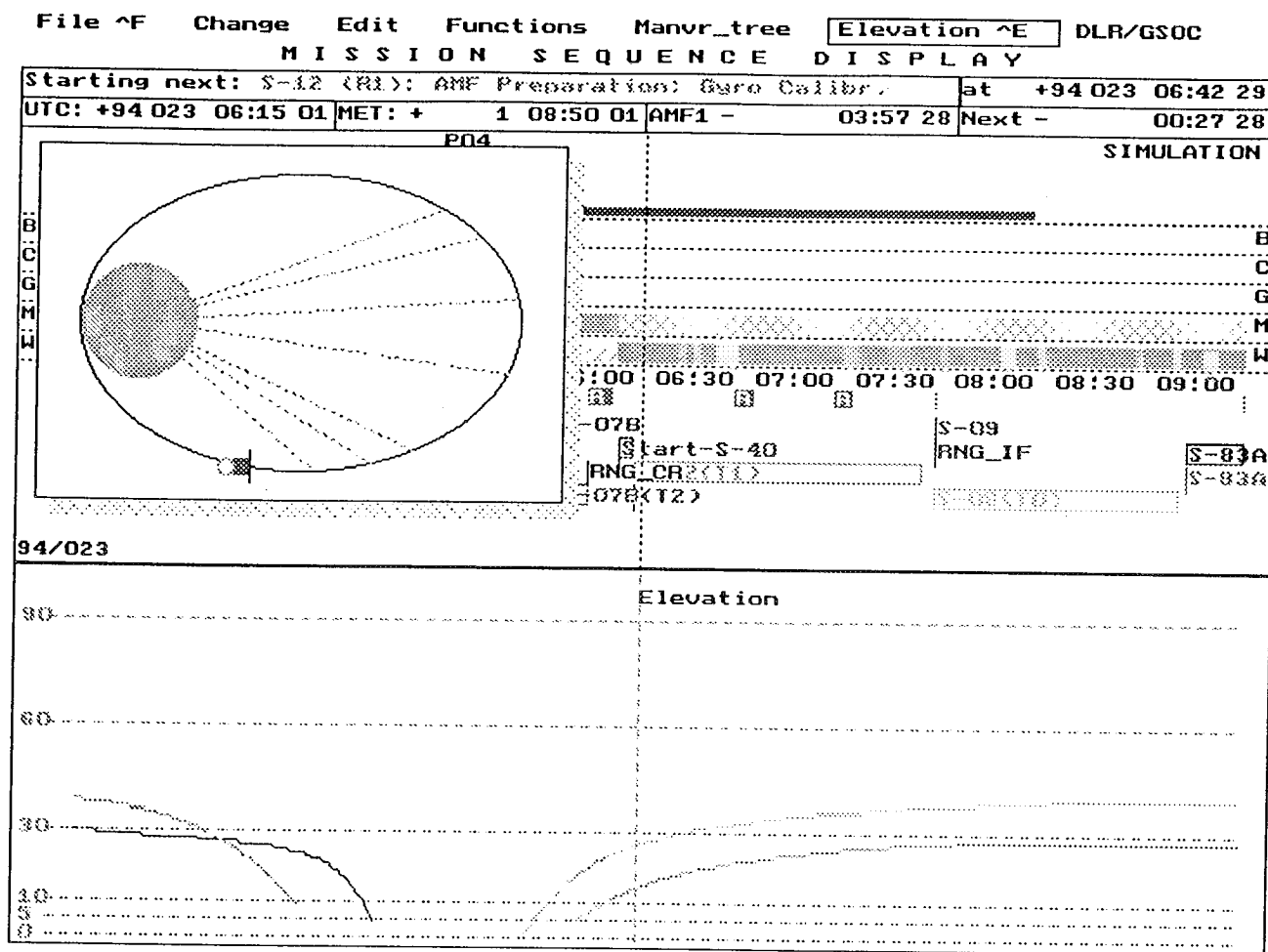


Figure 3: Graphical sequence editor. The station elevation angles, the S/C position and orbit geometry are optional windows.

4.3 SEQUENCE GENERATOR OUTPUTS

Main products of the Sequence of Events Generator are printouts of the Flight Operations Procedures and the Sequence of Events as described above. These may be printed completely or as special extracts. Additionally various outputs are generated making use of its features and the immense amount of information stored in the affected databases:

- Configuration Matrix:

For each dedicated step in the mission timeline the SOE generator can determine the nominal status of the S/C configuration. The respective telemetry values can be output in a configuration matrix file which is linked to the online telemetry processor. On request the processor compares this matrix with the actual S/C data and indicates any deviations. Configuration check files are prepared

in advance for each procedure as reference for start-up configuration checks as well as for major steps in the mission for go/no-go decisions.

- TC file generation:

The SOE generator provides a function to generate files of all telecommands for each single procedure. These files can be loaded directly into the command system where they may be released either manually or automatically with the radiation time defined by the SOE generator.

- Mission Timeline Display:

During the missions it was found that the Graphical Sequence Editor output provides an excellent general survey of the actual mission sequence. Therefore the display is projected onto a wall screen throughout the whole mission. The graphic is permanently updated by the actual time and shows all information related to orbit, station visibilities and procedures as described earlier. The actual status, history and future activities are displayed in a range corresponding to the selected resolution. Orbit related information is automatically updated by input files of the latest orbit predictions. In case of deviations from the original schedule the amount of expedite or delay can be entered and the graphic is shifted accordingly.

5. SUMMARY

The Sequence of Events Generator is a powerful instrument to prepare and guide all LEOP operations of geostationary spacecraft. This database oriented tool ensures easy, quick and safe generation of consistent mission operations documentation. In addition it provides some useful operational features and outputs. The flexibility of the application software and database structure allows to implement it also for other missions than geostationary positioning. At GSOC it has already been adapted for scientific missions as ROSAT and EXPRESS.

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* Presented in Poster Session